Challenges Facing Grid Integration of FC/ Hydrogen Technologies

"NREL Energy Systems Integration Facility (ESIF) Workshop"

Combustion Fuel Cells Distributed Power

ADVANCED POWER & ENERGY PROGRAM
UNIVERSITY of CALIFORNIA · IRVINE

Jack Brouwer
Associate Director

August 30, 2012

Outline

- Some thoughts on Grid Integration Challenges
- EXAMPLE: Irvine Smart Grid Demonstration (ISGD)
- Fuel Cell and Hydrogen Production Dynamics & Control

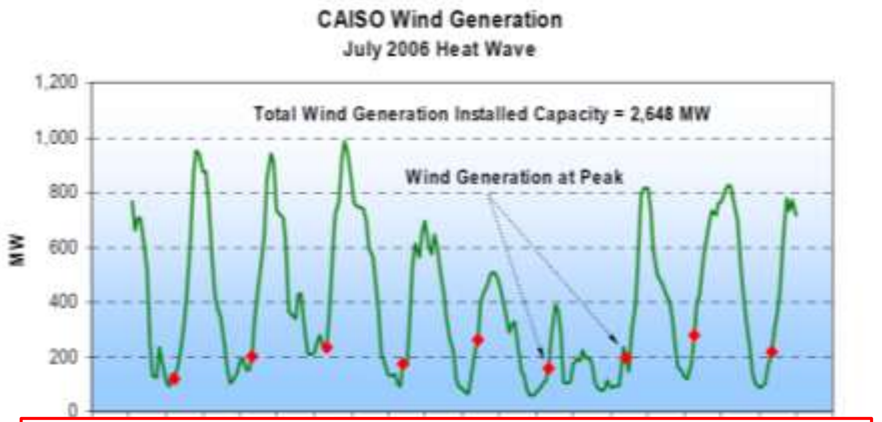
Grid Integration Challenges

Policy challenges:

- **Integration requirements different in each state**
- **Tariff / Rate Structure Challenges**
  - Departing Load charges
  - Demand charges
  - No Net-Metering
  - Co-Metering (Wholesale vs. Retail price)
  - No structures for additional benefit payments
    - Power quality
    - Power factor correction
    - Demand response
    - Virtual utility response
- **Utility Design / Review costs**
- **Metering & Interconnect Switchgear costs**
- **Islanding rules**

Grid Integration Challenges

Wind Power – Example of Non-Coincidence with Peak

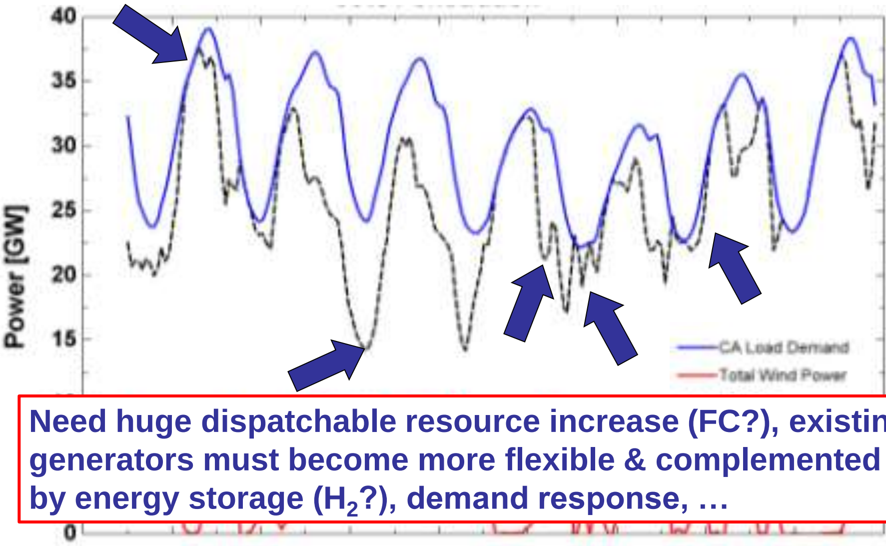


Need some energy storage and/or dispatchable power to shift the resource to match demand

CAISO, 2007

Grid Integration Challenges

Energy Deployment Model: 33% Wind Penetration

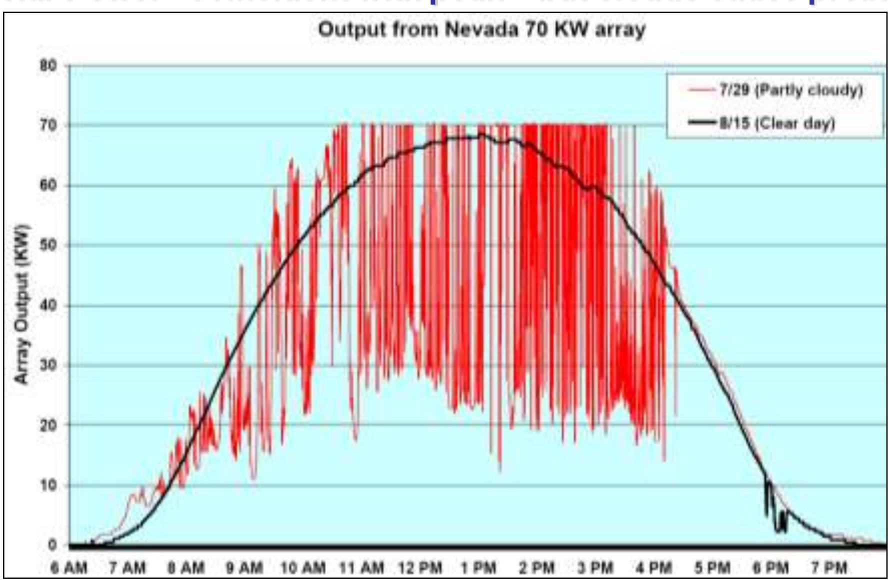


Need huge dispatchable resource increase (FC?), existing generators must become more flexible & complemented by energy storage (H_2?), demand response, …

July, 2006 data

Grid Integration Challenges

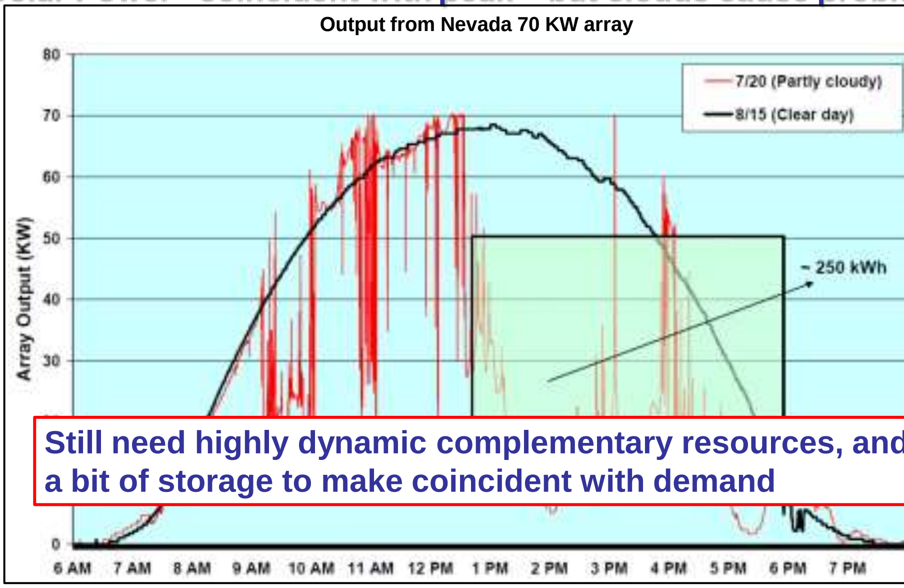
Solar Power ~coincident with peak – but clouds cause problem



SunPower, Inc., 2008

Grid Integration Challenges

Solar Power ~coincident with peak – but clouds cause problem



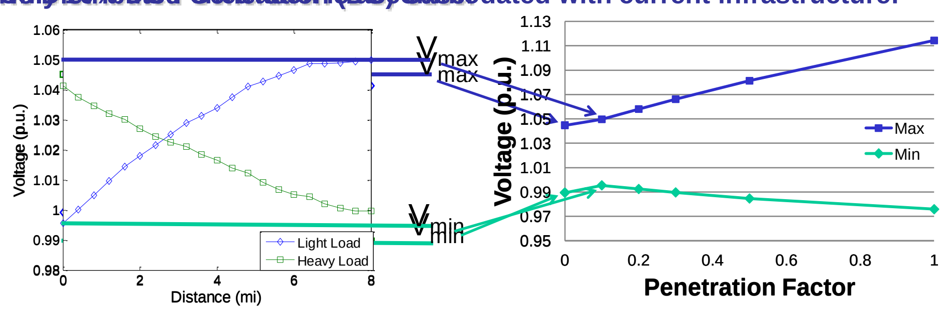
Still need highly dynamic complementary resources, and a bit of storage to make coincident with demand

SunPower, Inc., 2008

Grid Integration Challenges

Circuit Operation/Control Challenges: Voltage Regulation

- No Distributed Generation (DG) Case:
- Only 10% DG Penetration is accommodated with current infrastructure:



- Use load-tap changing (LTC) transformer to control substation voltage

What happens when we add PV to this distribution circuit?

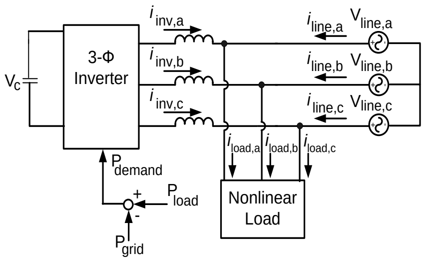
- Penetration Factor = DG capacity / Circuit baseline

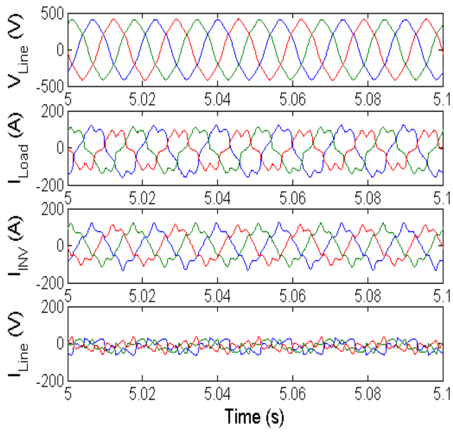
Two-way power flow, high penetration of loads (e.g., EVs) or generation (e.g., FC systems) pose capacity challenges

Grid Integration Challenges

Inverter Interconnection & Harmonics: Baseline case:

- Examine inverter-load relationship
- DG following measured building load (non-linear)
- Inverter-only
- Assume Pgrid = 10kW



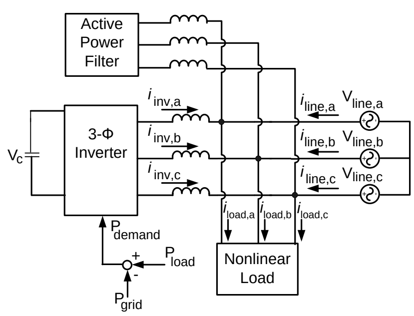


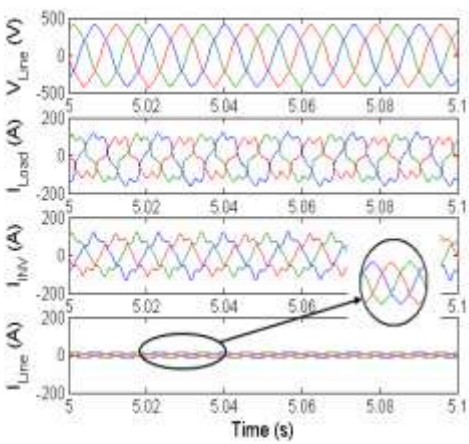
Inverter-only design is insufficient to compensate harmonics

Grid Integration Challenges

Inverter Interconnection & Harmonics: APF case:

- Infinite load-following
- Add active power filter (APF)
- APF provides compensation current

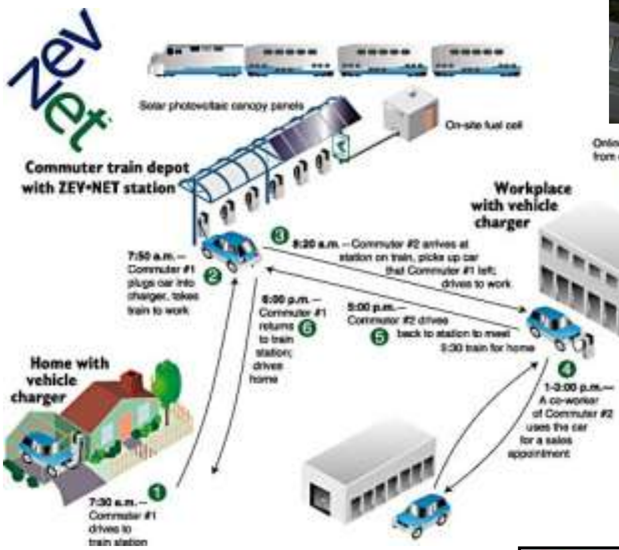




Addition of APF reduces undesirable line current harmonics

Grid Integration Challenges

EVs: Resource or Capacity Challenge?

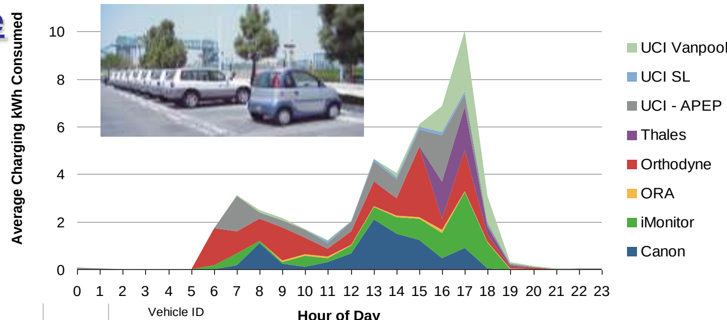


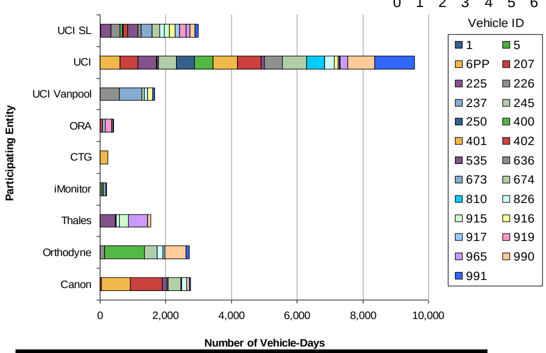
TOYOTA

Grid Integration Challenges

Vehicle battery use for grid support (“V2G”)

- Interconnection
- Battery Life
- Distribution circuit overload





UCI Mobility & Charging Data (from ZEV•NET)

Charging profiles w/o “Smart Grid” are not encouraging

Outline

- Some thoughts on Grid Integration Challenges
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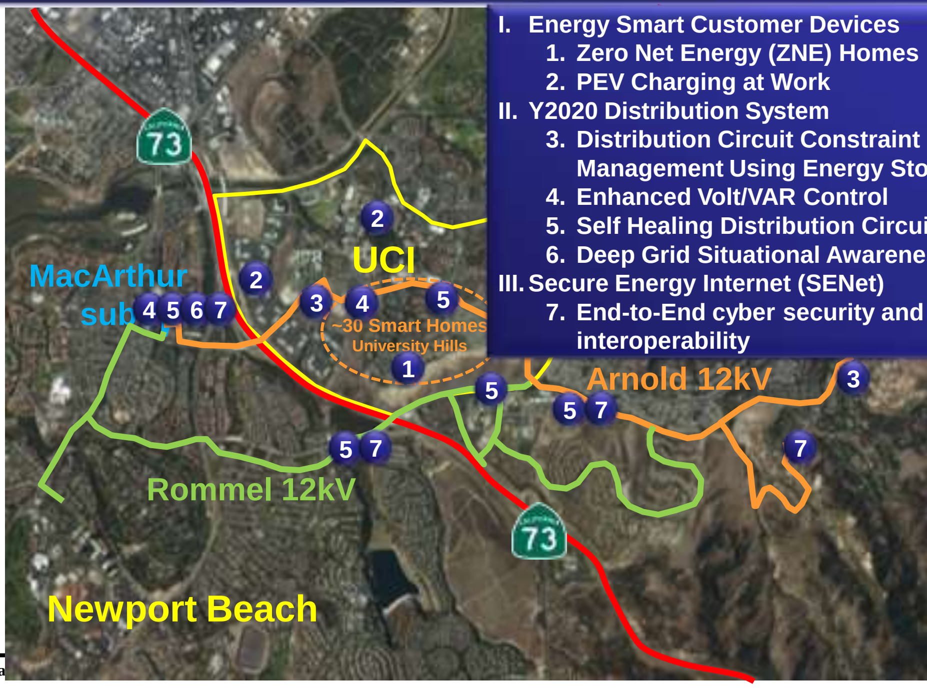
Irvine Smart Grid Demonstration (ISGD)

Project Team led by Southern California Edison (SCE):

- UC Irvine – energy conversion device testing, optimization and benefits analysis, faculty housing coordination
- GE – advanced appliances, EMS, smart inverters
- A123 Systems – battery storage
- SunPower Corp. – solar photovoltaic systems
- Itron Inc. – SmartConnect™ metering infrastructure
- EPRI – analysis, simulation, data acquisition
- USC – DARPnet security and interoperability protocols
- Cal Poly Pomona – curriculum development

Irvine Smart Grid Demonstration (ISGD)



- I. Energy Smart Customer Devices
  1. Zero Net Energy (ZNE) Homes
  2. PEV Charging at Work
- II. Y2020 Distribution System
  3. Distribution Circuit Constraint Management Using Energy Storage
  4. Enhanced Volt/VAR Control
  5. Self Healing Distribution Circuits
  6. Deep Grid Situational Awareness
- III. Secure Energy Internet (SENet)
  7. End-to-End cyber security and interoperability

Irvine Smart Grid Demonstration (ISGD)

- **Evolution of Home Energy Efficiency Technologies in ISGD**

Test Case	Energy Efficiency Level*	Home Area Network†	PV	EVSE	PEV (non-commun-icating)	Home Storage	PEV (commun-icating)	# of Homes
Control	-	-	-	-	-	-	-	~10
2012	35%	Yes	Yes	-	-	-	-	~10
2015	55%	Yes	Yes	Yes	Yes	Yes	-	~10
2020-ZNE	65%	Yes	Yes	Yes	Yes	Yes	Yes	~10

* above 2005 Title 24 level

† includes in-home displays, programmable, controllable thermostats, energy management systems, smart appliances, Edison SmartConnect™ meters

EVSE – electric vehicle supply equipment

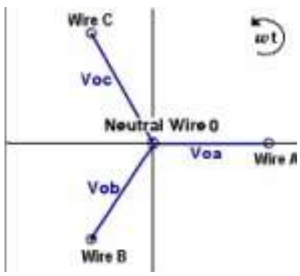
PEV – plug-in electric vehicle

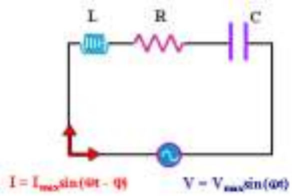
PV – photo-voltaic

ISGD Communication & Control Technologies

Advanced Sensing and Measurement

- Smart meters – Advanced Metering Infrastructure (AMI)
- Cost-effective sensing and energy measurement for home automation and smart appliances
- Distribution network sensing
  - Monitor voltage, frequency, angle, component temperature, weather conditions such as irradiance, wind velocity, and ambient temperature
- Transmission system sensing – phasors/synchrophasors





$$Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

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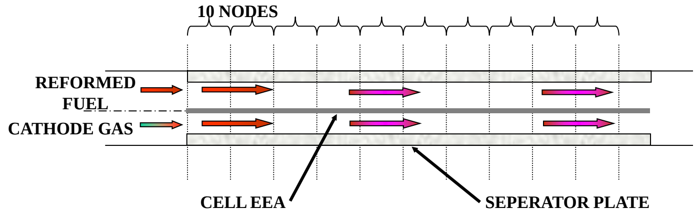
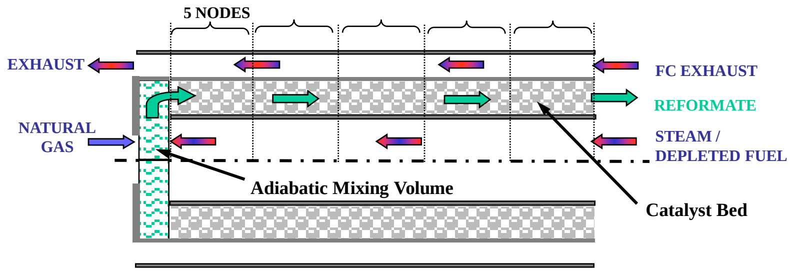
Sample Dynamic Simulation Module Geometries

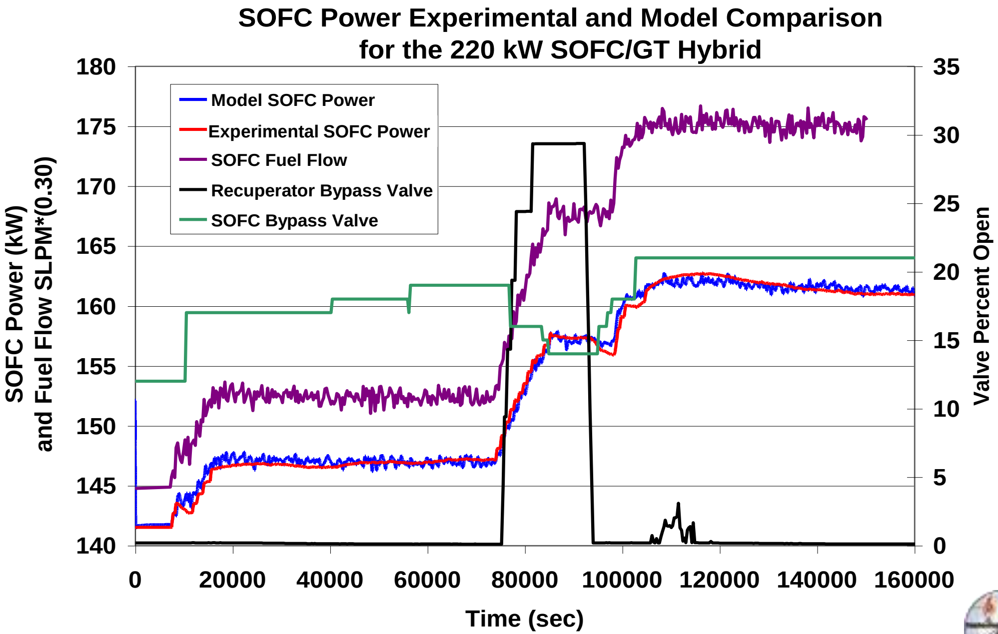
- **Planar SOFC with 10 Discrete Computational Nodes**
  - Anode Gas, Cathode Gas, Cell EEA, Separator Plates



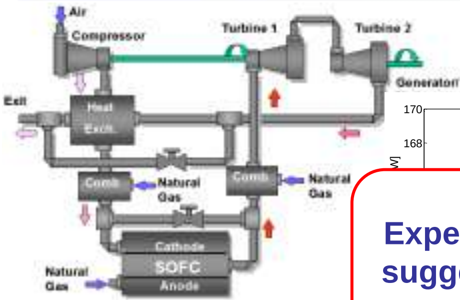
- **Reformer Module with 5 Discrete Computational Nodes**
  - Anode Off-Gas Recycle, Fuel Mix, Combustor HX, Catalyst Bed



Dynamic Simulation: 220kW SOFC/GT System

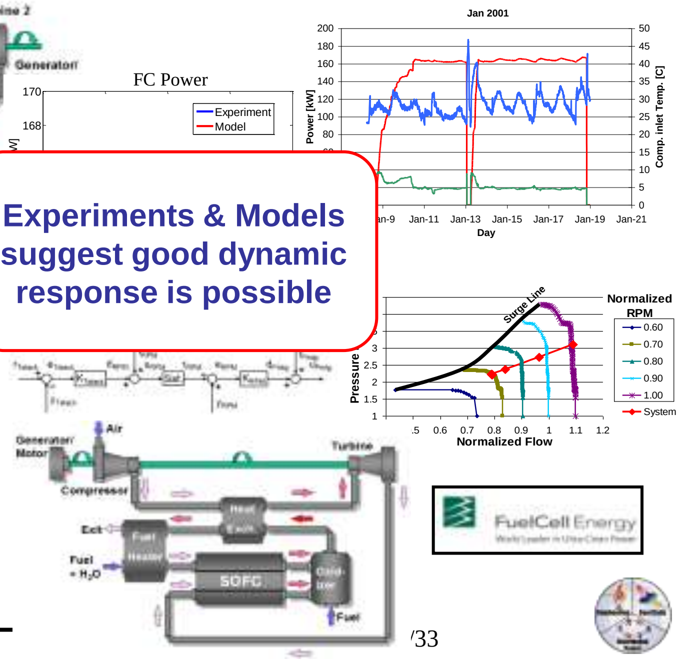


Integrated Fuel Cell System Dynamics



SIEMENS

EDISON



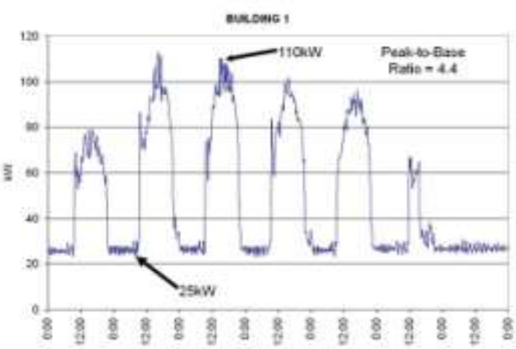
Experiments & Models suggest good dynamic response is possible

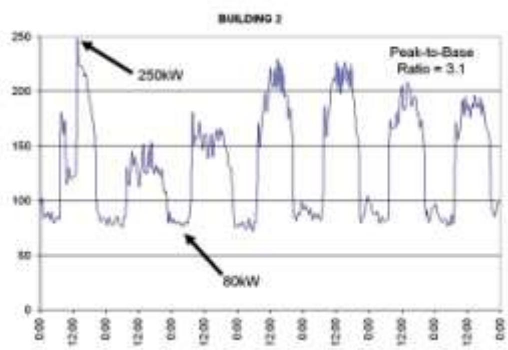
FuelCell Energy

Building Energy and Controls

Measure Dynamic Loads and CCHP Performance

- Measured commercial building dynamic loads





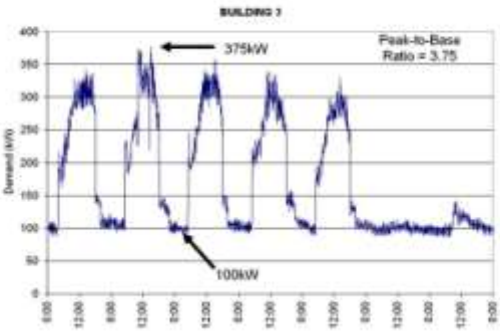
low computer use office space

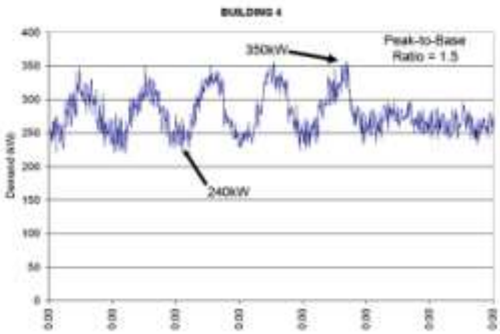
call and service center

Building Energy and Controls

Measure Dynamic Loads and CCHP Performance

- **Measured commercial building dynamic loads**



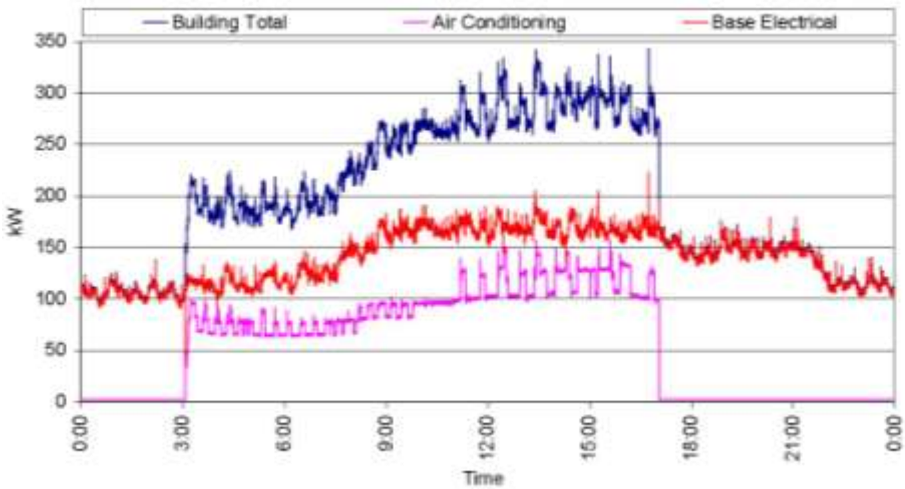


computer intensive office **data center**

Building Energy and Controls

Measure Dynamic Loads and CCHP Performance

- **Commercial Office Building "High Resolution" Data**



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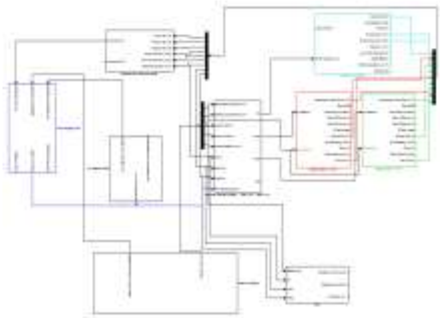
Building Energy and Controls

Simulate Existing CCHP Performance

- **Example of integrated CCHP system and Simulink® embodiment (Meacham et al., 2006)**

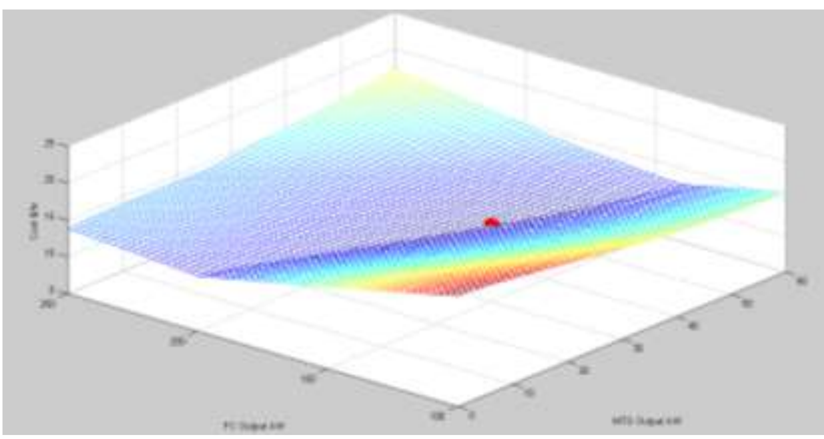


Building Energy and Controls

Develop Novel Control Algorithms

- **Previous algorithm example (Meacham et al., 2006)**

$$Cost = (P_{bldg} - P_{DG})C_e + \left(\frac{P_{DG}}{\eta_{DG}(P_{DG}, T_{amb})}\right)C_{NG} + K_{ws}(Th_{bldg} - Th_{DG}(P_{DG}, T_{amb})EFF_{DG})\left(\frac{C_e}{EFF_{comp}}\right)$$



Dispatchable Renewable Power from Fuel Cells

Steady-State Success (only)

Inland Empire Utilities, CA

Palmdale, CA – Waste-water

Tulare, CA – Waste-water treatment

Pleasanton, CA
Waste-water

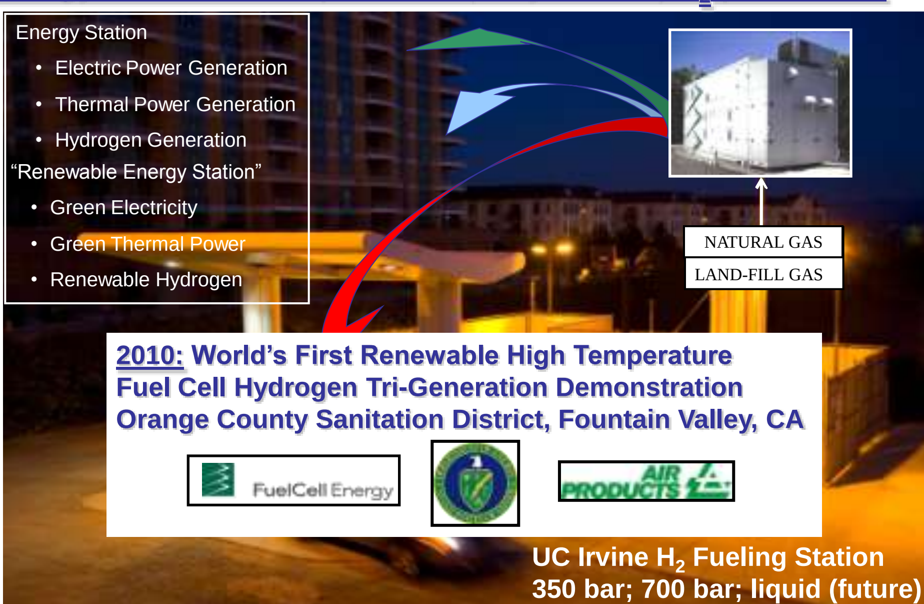
King County, WA
Waste-water plant

Sun City, CA – Waste-water treatment

Santa Barbara, CA – Waste-water treatment

Enable Local Hydrogen Fuel Provision

Energy Station Concept – local (& dynamic?) H_2 production



Energy Station
- Electric Power Generation
- Thermal Power Generation
- Hydrogen Generation

"Renewable Energy Station"
- Green Electricity
- Green Thermal Power
- Renewable Hydrogen

NATURAL GAS
LAND-FILL GAS

2010: World's First Renewable High Temperature Fuel Cell Hydrogen Tri-Generation Demonstration Orange County Sanitation District, Fountain Valley, CA

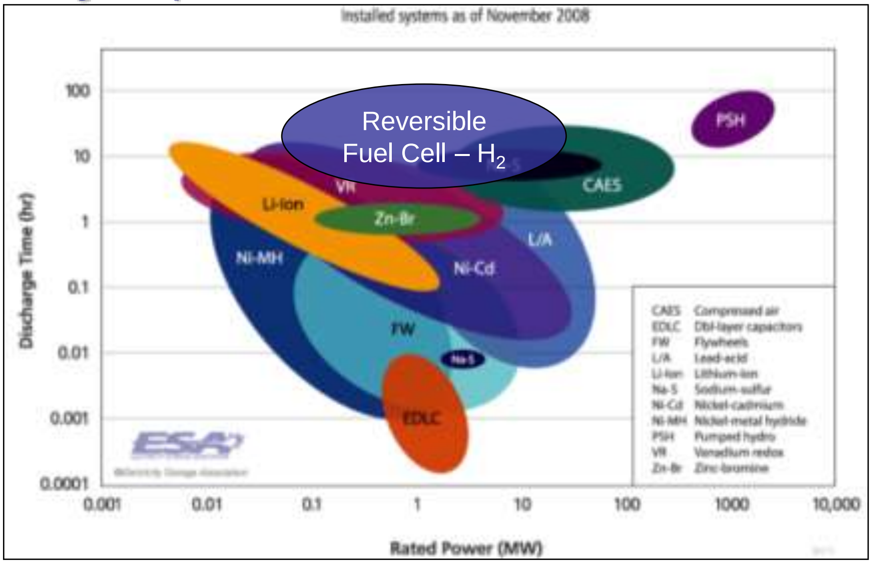
FuelCell Energy

AIR PRODUCTS

UC Irvine H_2 Fueling Station
350 bar; 700 bar; liquid (future)

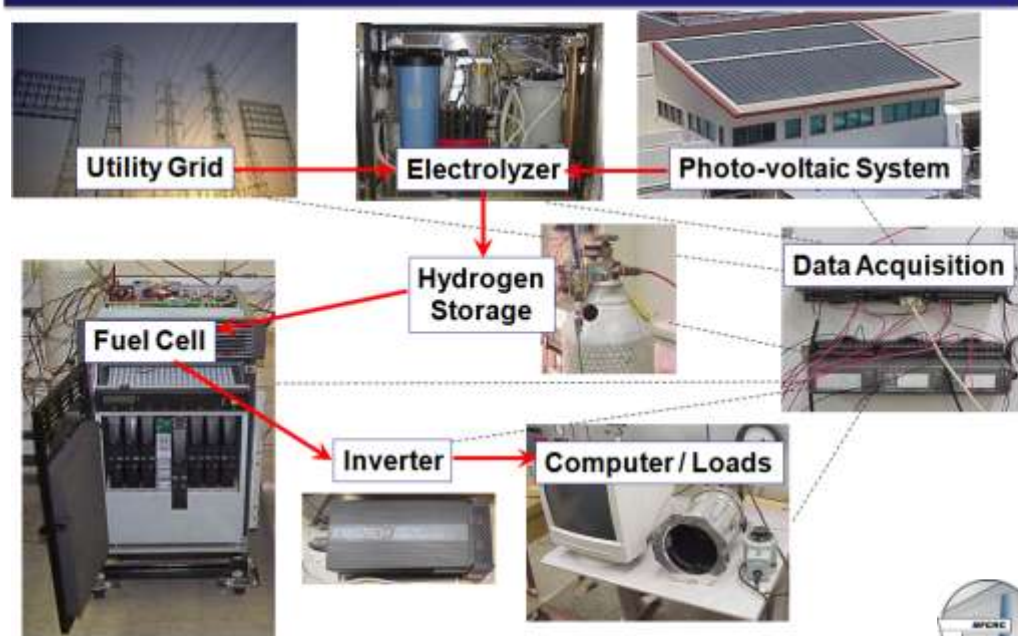
Energy Storage Technology Required

- **Rating Comparison**



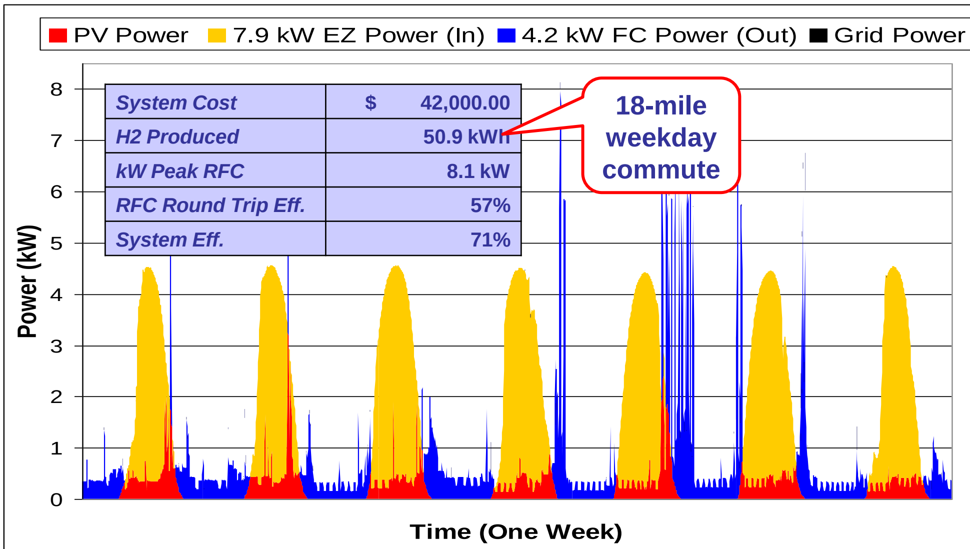
Electricity Storage Association, 2009

Renewable Fuel Cell Systems Research



Renewable Fuel Cell Systems Research

4.2 kW RFC Supply & Demand Power Flow:



Hydrogen Energy Storage

Solar Hydrogen Backup Power System
Los Alamitos, CA

- PV: 10kW- 60 Sharp 175 W, 15,682 kWh Annual Basis
- Proton Energy Hogen S40RE electrolyzer
- 4 5kW GenCore Fuel Cells
- 2- APC Symmetra LX-8 -16 KVA batteries

Hydrogen Energy Storage

Pipeline transmission may be preferred to wires

Co-benefit of long-range zero emissions transportation fuel

THANKS for Your Attention!

Questions?

Combustion

Fuel Cells

Distributed Power

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